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Intelligent Hoist Control Based on Computer Vision

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Abstract: Construction hoists are essential equipment for vertical lifting of workers and materials on construction sites, and their efficient operation significantly impacts the success of construction projects. To optimize hoist operation, it is crucial to accurately understand the call situation on each floor (i.e., the external waiting state) and the internal state of the hoist. This study aims to use object detection technology to monitor the status of workers and materials waiting on each floor, as well as the boarding state inside the hoist in real-time. Subsequently, by utilizing the real-time gathered information, a model was developed to reduce the number of stops, thereby demonstrating the potential of object detection technology in reducing the hoist's transportation time. The research results show that it is possible to determine the number of workers, the types of materials, and the quantity of materials to board the hoist using object detection, and to derive an optimized route. Consequently, it demonstrates that the use of object detection can reduce the transportation time of the hoist, thereby improving its operational efficiency.

Key words: Intelligent Hoist Control, Construction Hoist, Computer Vision, Object Detection

1. INTRODUCTION

In construction sites, hoists play a key role in the vertical lifting of workers and materials. Due to the constraints in transporting resources, efficient logistics management in construction sites requires meticulous planning in the operation of equipment. [1] [2] Therefore, the efficient operation of hoists significantly impacts the timely procurement of materials and overall productivity of construction projects. Efficient operation of hoists means minimizing the waiting and transportation times after a hoist call, and reducing unnecessary movements to enhance resource transportation efficiency and energy efficiency. However, current hoists are operated based on intuition and experience by dedicated hoist drivers. In high-rise sites where multiple hoists operate simultaneously, the lack of communication between multiple drivers can lead to redundancy and unnecessary calls and movements, significantly reducing the efficiency. To address this, the real-time and accurate understanding of the status of workers and materials waiting after a call on each floor (number of personnel, location, quantity of materials, type of materials, etc.), and considering the lifting capacity of the hoist, can support accurate dispatching and operation, thereby reducing hoist transportation time.

In relation to this, there have been studies that involve inputting the target floors before boarding or using object detection. However, these studies only considered the situation inside the hoist and did not take into account the external conditions. Moreover, there was another limitation that only waiting personnel were considered whereas the materials were neglected. To overcome these limitations, it is necessary to conduct object detection not only inside but also outside the hoist and to train the computer with images of materials, so it can recognize not only people but also materials. Therefore, the aim of this research is to use computer vision technology, to be exact object detection, to real-time monitor the status of workers and materials waiting on each floor at construction sites and those boarding the hoist, and to demonstrate that this can reduce the number of stops made by the hoist. To accomplish this goal, the study focuses on identifying the number of passengers inside the hoist, the waiting personnel outside, and the status of waiting materials. This gathered information is then applied to a newly proposed hoist algorithm, aimed at reducing the hoist's transportation time. By doing so, the research seeks to contribute to a decrease in the overall construction duration, enhancing efficiency in construction site operations. This study demonstrates, through two scenarios, how object recognition technology, capable of assessing the conditions inside and outside the hoist as well as in the waiting areas of each floor, can effectively reduce the number of stops made by the hoist. This approach highlights the potential of using advanced technology to enhance the operational efficiency of hoists in construction sites.

2. LITERATURE REVIEW

2.1. Previous Research on Hoist Optimization

The efficiency of lifting equipment varies with the height of the building, and the plan for resource transportation significantly affects the overall duration of the construction project. [3] [4] [5] Currently, in construction project sites, the operation of hoists is manually conducted by dedicated hoist drivers. However, these drivers can only understand the external conditions (such as the number and type of people waiting at the call floor) upon arriving at the respective floor. This method makes it difficult to anticipate external situations in advance, leading to unnecessary calls and movements. This can increase the time taken for material and personnel transportation using the hoist, potentially causing disruptions in the procurement plan. Consequently, such inefficiencies can lead to delays in the overall project and a decrease in work productivity.

To solve these issues, a method where waiters at the hoist call floor input their destination floor before boarding the hoist has been researched. Six types of sensors were installed inside the hoist, and a process for selecting the optimal hoist was developed by collecting operational information from each sensor. [6] However, this method only takes into account the target floors of those waiting, forming the hoist operation algorithm based solely on this aspect. It presents a limitation in that it fails to connect the scenarios inside and outside the hoist, thereby overlooking the comprehensive operational dynamics.

2.2. Potential of Computer Vision in Optimizing Hoist Operation

Computer vision, a field of artificial intelligence, enables the extraction of meaningful information from various visual inputs such as digital images and videos through computers and systems. By leveraging this technology, it is possible to extract information as an alternative to traditional human visual assessment, enabling the execution of tasks based on the data gathered from these visual inputs. Object detection, a subset of computer vision, can identify various objects, including people, animals, and vehicles. With the potential of computer vision, there has been a surge of interest in its application across various academic and industrial fields. In the construction industry, particularly, object recognition has been incorporated into a range of studies. These include managing safety on construction sites by detecting whether safety helmets and harnesses are being used, and preventing accidents through the recognition of obstacles.

In the case of construction hoists, research has been conducted using object detection technology to understand the number of passengers inside the hoist and the waiting personnel outside. Precedent studies have demonstrated how object detection can detect helmets worn by workers, enabling the efficient operation of hoists by understanding the number and information of users inside the hoist and waiters at each floor. [7]

However, such algorithms only account for the number of personnel inside and outside the hoist, neglecting the consideration of construction materials. This presents a considerable shortcoming, given that hoists in construction sites are tasked not just with transporting workers but also a variety of materials, including formwork and curtain walls.

Therefore, this study aims to demonstrate the ability to distinguish and recognize workers and materials using data trained in person, thereby understanding the situations both inside and outside the hoist. The research was conducted by differentiating two scenarios: identifying the presence of materials, and comparing the situations inside and outside. The two newly proposed hoist algorithms were compared with the existing hoist algorithms in terms of transportation time, to evaluate the utility of object detection.

3. COMPUTER VISION BASED ADAPTIVE HOIST CONTROL ALGORITHM

The overall algorithm proposed in this study is depicted in Figure 1. Whenever a new call is made, cameras perform object detection in two spaces: outside the hoist, observing the waiting situation on each side, and inside the hoist. Subsequently, based on the recognized object information, a series of processes are carried out to derive a reorganized list of stop floors, which then dictates the operation of the hoist. This reorganized list of stop floors refers to a list with fewer stops compared to the original one. In other words, the algorithm prevents unnecessary stops that would occur in the conventional operation mode, thereby reducing the number of hoist stops. There are two scenarios that can demonstrate this effect.

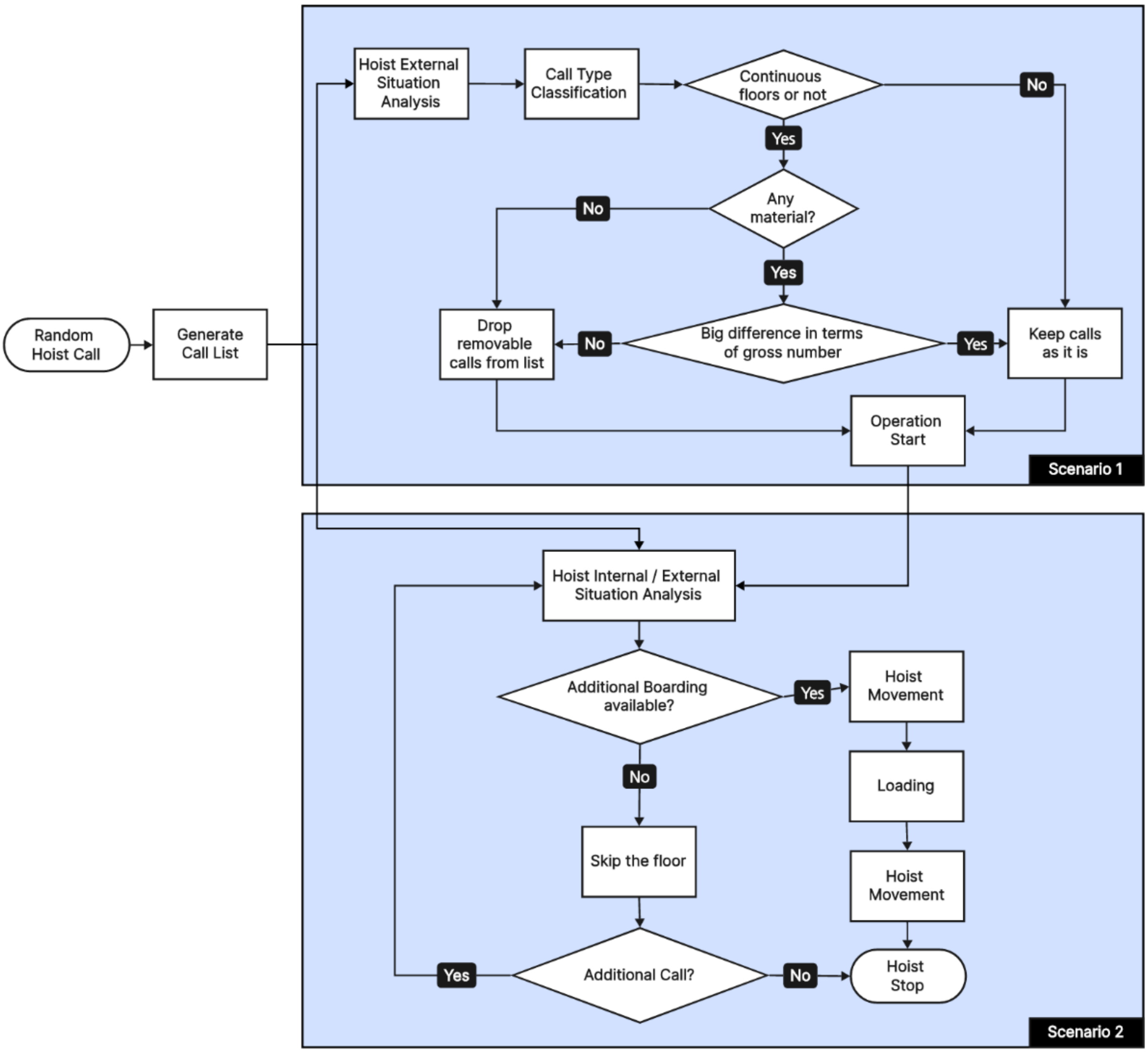

Figure 1. Hoist Operation Algorithm

In the first scenario, the hoist prioritizes the presence of materials when responding to calls from consecutive floors, but also considers the total number of people to re-adjust the stopping floors. When there are calls from consecutive floors, object detection is used to check for the presence of materials on each floor. Based on this, the hoist prioritizes stopping at floors with materials, while opting not to stop at floors where only people are waiting. Yet, special consideration should be given when there are plenty of people waiting regardless of the presence of materials. In such cases, one unit of material is considered equivalent to a set number of people, facilitating the calculation of the total number of individuals waiting at each floor. If the count of people waiting on floors without materials significantly exceeds those with materials, the hoist will stop at those floors despite the absence of materials.

In the second scenario, the hoist reduces the number of stopping floors by skipping the floors where it cannot pick up waiting personnel or materials. When a new call is made from a certain floor, object detection is used to determine the additional weight that can be boarded inside the hoist. Should there be additional capacity for boarding, the hoist will proceed to the calling floor to board the waiting workers (and materials). It then moves towards the designated target floor to carry out the following operations. In cases where no further boarding is feasible, the hoist will decline to respond to the call.

4. CASE STUDY

In this section, we present the detailed information of the two scenarios mentioned earlier and the results of executing Python codes which reflect the scenarios. By comparing the current algorithm, which stops at all floors, with the two newly proposed algorithms in terms of transportation time, we have evaluated the efficiency and suitability of the algorithms presented in this study.

4.1. Test Scenario

The objectives and assumed situations of the two algorithms proposed in this study are summarized in Table 1. In Scenario 1, the decision to stop the hoist depends on whether the waiting personnel at the call floor is carrying materials. On the other hand, in Scenario 2, the decision to stop is based on the consideration of weight overload inside the hoist. As material transportation is crucial during working hours in construction sites, Scenario 1 grants boarding priority to those transporting materials. As a result, people waiting without materials may be asked to move to different floors depending on the situation. On the other hand, Scenario 2 considers times like peak hours (such as commuting times, before and after lunch), when the total number of waiting personnel and materials exceeds the hoist's capacity. During peak times, when personnel movement is crucial and demand surges, the number of people unable to board increases compared to normal conditions. To prevent unnecessary stops that commonly occur in such cases, Scenario 2 determines the boarding of waiting personnel at each floor based on the internal situation of the hoist.

Table 1. Scenario Classification

		Scenario 1	**Scenario 2**
Objective through Object Detection	Comparison Range	Consecutive Upper and Lower Floors	Inside and Outside of the Hoist
	Distinguishing Factors	Presence of Materials	Additional Boarding Capability on the Hoist
Assumed Situations	Inter-floor Movement of Waiting People	Required Depending on the Situation	Not Required
	Boarding of Waiting People in Single Move	All Board	Partially Omitted Depending on the Situation
	If Applied at the Same Time	Normal Times	Peak Time

4.2. Test Methods

4.2.1. Operation Time Calculation Formula

Referring to previous studies, the operating time of the hoist (T) has been defined as Formula 1. [8] T_M represents the operating time of the hoist, and T_L denotes the total loading/unloading time for resources such as workers and construction materials.

$$T = T_M + T_L \tag{1}$$

In addition to Formula 1, previous studies have considered different acceleration and deceleration times based on the type of hoist. This consideration is particularly crucial for super high-rise buildings, which differ in height and number of floors. Therefore, T_M in Formula 1 is calculated by adding T_{os}, which represents the moving time at operation speed, the constant T_a for acceleration time, and the constant T_d for deceleration time. Formula 2 is as follows:

$$T_M = T_{os} + T_a + T_d \tag{2}$$

The moving time (T_{os}) is calculated by adding the rated speed operation time (T_n) for the number of floors excluding the stopping floors ($F_g - F_s$) and the repeated acceleration and deceleration times for each stopping floor. The total loading time of resources (T_L) can be calculated as the loading time of resources (T_l) at each floor, repeated for the number of stopping floors. This can be represented as Formulas 3 and 4.

$$T_{os} = \left(F_g - F_s\right) \cdot T_n + F_s \cdot (T_a + T_d) \tag{3}$$

$$T_L = F_s \cdot T_l \tag{4}$$

4.2.2. Simulation Condition

The common conditions set for both scenarios are as follows. The hoist starts from the top floor and moves to the revised calling floors according to each algorithm before arriving at the first floor. The building has a total of 20 floors, and the floors making the calls, along with the waiting personnel and materials, are randomly generated. To prevent too few or too many calls from being generated, a maximum of 12 and a minimum of 5 calls are set. Regarding the hoist's operating speed, the normal speed travel is set to 3 seconds per floor, the acceleration and deceleration times are both 2.9 seconds, and the loading time for lifting materials is set to 10 seconds.

In Scenario 1, the hoist re-adjusts the stopping floors by considering both the presence of materials and the total number of people. In calculating the total number of people, one unit of material is considered equivalent to three people. When the final count shows that the number of people waiting on floors without materials exceeds twice the number on floors with materials, the hoist will stop. In Scenario 1, it is assumed that a single hoist carries all individuals and materials in one trip down to the first floor.

Scenario 2 utilizes object detection to compare the load inside and outside the hoist and determine whether to stop. It identifies the weight of each person and material, assuming the average weight of an adult male to be 75kg, and approximate weights for each material (Euroform: 15 kg, Scaffold Tube: 8 kg). Based on this, the number of recognized people and materials is multiplied by the assumed weights to calculate the total weight inside and outside the hoist.

4.3. Test Results

The results of executing the code for Scenario 1 are as shown in Figure 2. Calls were randomly generated in the format of (floor of call, number of people, number of materials). Calls were made from floors 2, 3, 4, 8, 12, 13, 15, and 20, and according to the reorganizing algorithm, the hoist stationed at the 20th floor will not stop at the 3rd floor. While the original algorithm, which stops at every called floor, took 144.6 seconds to complete all operations, the hoist using the algorithm took 125.8 seconds, resulting in a 13.00% reduction in total transportation time.

```
Randomly generated calls: [(3, 4, 1), (20, 1, 2), (8, 10, 1), (4, 4, 5), (15, 0, 4),
(2, 1, 5), (12, 9, 5), (13, 2, 2)]
Final stopping floors for optimized hoist: [2, 4, 8, 12, 13, 15, 20]
Operation time for original hoist: 144.6 seconds
Operation time for optimized hoist: 125.8 seconds
Time reduction: 13.00%
```

Figure 2. Python Result for Scenario 1

Figure 3 presents the execution results of the code for Scenario 2. There were calls from floors 18, 16, 5, and 3. According to the revised algorithm, the hoist stationed at the 20th floor only stops at floors 18 and 16 on its first trip. It does not stop at floors 5 and 3 during this trip due to reaching its maximum weight capacity. While the original algorithm, which stops at every called floor, took 142.6 seconds to complete all operations, the hoist using the algorithm took 132.2 seconds, resulting in a 7.29% reduction in total transportation time.

```
Randomly generated calls with people and materials:
Floor 3: 3 persons, Support
Floor 5: 3 persons, Euroform
Floor 16: 3 persons, Euroform
Floor 18: 2 persons
Floor 20: True persons
All called floors: [3, 5, 16, 18, 20]
Final stopping floors for optimized hoist: [20, 18, 16, 1, 5, 1, 3, 1]
Operation time for optimized hoist: 132.2 seconds
Operation time for original hoist: 142.6 seconds
Time reduction: 7.29%
```

Figure 3. Python Result for Scenario 2

Table 2 illustrates the outcomes of numerous iterations of the codes for Scenarios 1 and 2. The results of 50, 75, and 100 repetitions for each algorithm were reviewed five times. The results of each execution were documented in the format of (average call count / average reduction rate). The overall average calculations revealed that the transportation time exhibited a reduction rate of 14.43% for Scenario 1 and 7.68% for Scenario 2.

Table 2. Repetition Result for Scenario 1&2

Trial	Scenario 1			Scenario 2		
	x50	x75	x100	x50	x75	x100
1	8.7 / 15.49	8.3 / 14.80	8.7 / 14.60	9.0 / 8.39	8.6 / 7.63	8.3 / 7.48
2	8.8 / 15.81	8.8 / 14.48	8.8 / 14.93	8.4 / 7.02	8.2 / 5.90	7.8 / 6..94
3	8.5 / 15.59	8.2 / 13.00	8.5 / 14.50	8.7 / 6.60	8.3 / 7.18	8.3 / 6.67
4	8.0 / 13.75	9.0 / 14.96	8.3 / 13.91	9.2 / 8.24	8.7 / 7.71	8.5 / 7.50
5	8.1 / 13.78	8.1 / 13.55	8.4 / 13.29	8.0 / 7.94	8.6 / 7.03	8.7 / 7.68

5. CONCLUSION

Hoists play a crucial role in the vertical movement of personnel and materials in construction sites, and their efficient operation significantly impacts the overall productivity of construction projects. Currently, hoist operations mainly rely on the intuition and experience of the dedicated drivers, which can lead to decreased efficiency due to unnecessary calls and movements caused by lack of communication. This research sought to improve the efficiency of hoist operations by implementing object recognition technology to assess the status of workers and materials on each floor in real time. Therefore, The study utilized object recognition, a branch of computer vision technology, to determine the number of passengers within the hoist, the personnel waiting outside, and the status of materials in the queue. Building on this information, the study introduced an algorithm aimed at reducing the frequency of hoist stops, thereby demonstrating the potential to decrease the overall transportation time of the hoist.

The study verified how object detection technology, which monitors the situation inside and outside the hoist and in each floor's waiting area, can reduce transportation time and enhance the operational efficiency of hoists through two scenarios. The presented algorithms demonstrated a reduction in hoist transportation time for each scenario, thereby improving hoist efficiency. However, a limitation of this study is the use of a single hoist for simulation, which did not fully consider various situations and variables that could arise when multiple hoists are in operation. This might have led to the omission of analysis on different scenarios involving the interaction and collaboration among hoists. Future research could promisingly explore the use of object detection technology with other construction equipment beyond hoists, to verify whether it could generally increase the work efficiency of construction machinery.

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